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Usability Assessment of Displays for Dismounted Soldier Applications

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14. ABSTRACT

This report presents a usability assessment of scalable displays for dismounted robotic control applications. The assessment covered three components: display size, button features (e.g., size, location), and controllers for tele-operation. Twelve Soldiers participated in the assessment. Before the assessment, the Soldiers were trained on a larger version of the displays. They then used the three scalable display configurations to plan and execute a mission for an unmanned vehicle (UV). During the execution of the task, video was recorded and the experimenters asked scripted questions about the displays. Results showed that the Soldiers were successful in using the various display configurations to complete the UV task; however, all the Soldiers asked clarifying questions about how to plan the mission. These results suggest that the original and largest display design lacked design principles that were fully transferable to smaller displays. With respect to display size and button size, the interviews showed that a small display was preferred to the larger one used in training for dismounted operations. However, the buttons on the small display were difficult to use without a stylus. For mounted operations or during conditions when the Soldier would not have to be mobile, the larger display was preferred. This report discusses these results in detail, related theories, and the implications for designing effective scalable displays.

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dismounted Soldier; scalability; unmanned systems

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Contents

List of Figures

1. Introduction

As operational demands on Soldiers increase and with multiple new display technologies hitting the battlefield, advanced display technology will be needed. Advances include multi-modal displays, intelligent automation, and (of interest here) scalable technology. In the fullest sense, scalability is the tailored reception and transmission of mission-essential information at the appropriate level for the Soldier and in the appropriate form. A key design goal of any military system is to maximize the survivability and lethality of the Soldier-system in order to ensure mission success. Scalable design goes a step further and can be described as the synergistic interaction of the hardware equipment requirements, the seamless integration of distributed software agents, and for the Soldier, standardized system interactions and appropriate cognitive workload, which in turn support lowered learning requirements and increased situational awareness. This notion of scalability is especially relevant for the dismounted Soldier who will be controlling unmanned vehicles (UVs), will need to maintain his/her local security, and will complete routine tasks as the battlefield changes. The type of UV controlled from that display may change, depending on the mission or environment. The dynamic nature of the Soldier's environment suggests that the display should be scalable, which would minimize the Soldier's need to be familiar with multiple system hardware/software configurations. As displays are scaled, they should have minimal learning time, acceptable performance metrics for completing required tasks, low error rates, and high user satisfaction (Schneiderman, 1987).

The Robotics Collaboration Army Technology Objective (RC ATO) is addressing the scalability issue. The RC ATO is a joint effort by the Tank Automotive Research, Development and Engineering Center (TARDEC) and the U.S. Army Research Laboratory (ARL). Under this program, TARDEC and ARL are working to develop a common user interface for robotic control that maximizes multi-functional Soldier performance of primary mission tasks, minimizes unique training requirements by minimizing and standardizing required interactions and managing workload in the control of ground and air unmanned systems. We are developing and evaluating scalable interface concepts that facilitate the Soldiers' use of their robotic (i.e., unmanned) assets. TARDEC designed displays for dismounted applications with UVs. The dismounted displays provided basic tele-operation and mission planning capability. The capabilities of the displays were modeled on the existing Vetronics Technology Integration (VTI) crew station with modifications to support scalability. If the new versions of the displays meet scalability criteria, there should be minimal training requirements on the new system for an experienced operator. Further, performance should be at acceptable limits, and user satisfaction should be high.

Our goal was to provide an assessment of the scaled displays. We focused our assessment on three components of the display: display size, button features (e.g., size, location), and the controllers for tele-operation. In addition, we evaluated whether the displays supported the requirements of scalability, minimal training, and user satisfaction. To this end, trained VTI operators participated in this assessment, and objective performance and subjective feedback were obtained. The procedures used in this assessment provided a means for capturing information that TARDEC could use to build their displays and provide a foundation for our scientific research. This report presents the findings and suggestions from the usability assessment of these prototype dismounted displays designed by TARDEC at Fort Knox, Kentucky, from 10 July to 14 July 2006.

2. Display Design

The dismounted displays were versions of the mounted crew station, the VTI display, modified to support scalability. The modifications implemented to support scalability were the ability to

- Run on multiple operating systems, graphics systems, and hardware platforms;
- Not only stretch/shrink user interface control features but to also change the features into a form more appropriate for the intended display size;
- Configure a user interface to take advantage of target-specific input/output devices (e.g., audio output, speech input, touch screens, global positioning system [GPS] units); and
- Adapt an interface based on mission-specific needs (e.g., the tele-operation screen may increase in complexity and have more features for an off-road mission).

TARDEC created the displays using the following approach:

- Identified the tasks that need to be accomplished when the display is used;
- Defined a software language in which a user interface can be described while being completely device independent; this means
  - No use of pixel positions or sizes,
  - Using relative positions to group display features (e.g., buttons),
  - Associating function with display features so that informed decisions can be made in regard to adapting to missions,
  - Prioritizing widgets so that low importance features can be dropped or placed on sub-screens, and
  - Using a human-readable language such as extensible markup language.
- Created a toolkit that encapsulates the concepts described in the interface language;
- Created utilities that can

- Process the interface description language into a database,
- Process style configuration into a database, and
- Process configuration into a database with rules.

● Created a software scalability component to determine target hardware capability and adapt or scale the interface description to the hardware, taking advantage of hardware-specific input and output devices;

● Designed and implemented a new user interface builder tool that can be used to
  - Generate the interface description,
  - Display the interface as it would appear in various targets,
  - Define widget attributes, and
  - Generate user interface style configuration file; this allows the interface to be displayed in various differing styles.

For this assessment, the software was designed so that it could adapt to certain constraints, the size of the hardware (i.e., display size) and the hardware input (i.e., control modality for tele-operation). The scalable software was programmed to run on two displays:

1. Large Tablet Display (Display 1)

   Model: Xplore Technologies: iX104C2 display (see figure 1)

   Intel Pentium M 733 – 1.1 GHz

   10.4-inch extended graphic array transmissive liquid crystal display

   Display Size: 8.25 by 6.25 inches

   Button Size: 2.5 cm (wide) by 2.0 cm (high)

Figure 1. iX104C2 tablet PC.

2. Small Personal Digital Assistant (PDA) Display (Display 2)

Model: Transmeta Cursoe Model TM5800 (see figure 2)

1-GHz mobile processor

Display Size: 5 by 3.75 inches

Button Size: Two sizes

Small Buttons - 1.5 cm (wide) by 1.0 cm (high) (0 cm spacing)

Scaled down large buttons - 1.5 cm (wide) by 1.3 cm (high) (0.2 cm spacing)

Figure 2. Transmeta Crusoe model TM5800.

In addition to designing the software so that it ran on various display sizes, TARDEC implemented a discovery service feature. The display software searches the network for available features that can be used to control unmanned assets. The discovery service feature is a way the interface can adapt to the current mission or robotic asset. The discovery service feature that was assessed at Fort Knox was a tele-operation feature. UVs can be tele-operated with a traditional joystick (see figure 3). TARDEC designed an alternative to the traditional physical joystick, a software-based joystick (see figure 4). The software-based joystick was presented on the display and the operators used a stylus or finger to tele-operate the UV (i.e., TALON[1]). The discovery service feature for tele-operation worked in the following manner. If the physical joystick was plugged into the display, then the software-based joystick was longer functional and was removed from the display. If the physical joystick was removed, the software-based joystick became an active component on the display and the Soldier used it for tele-operation.

[1]TALON, which is not an acronym, is a registered trademark of Foster-Miller, Inc.

Figure 3. Physical joystick; Logitech[2] Attack 3 joystick.

Figure 4. Software-based joystick.

It is worth noting that the two dismounted displays, the tablet and the PDA, were designed to be as similar as possible to the mounted VTI crew station design; however, there are several technical differences:

1. VTI has three large portrait screens, each with a 1200 x 1600 resolution; dismount has two smaller form factors

[2]Logitech is a registered trademark of Logitech, Inc. The Logitech logo and the Logitech products referred to herein are the trademarks or the registered trademarks of Logitech.

    a. Tablet 1024x768
    b. PDA 800x600

2. VTI is capable of displaying two interfaces per screen with the ability to stretch the map interfaces to fill a full screen; dismount can only display a single interface at any one time.
3. There is only a single interface "look" for VTI; dismount has multiple "looks" based on target and configuration.
    a. VTI Look where the buttons and gauges are the same as VTI
    b. VTI Scaled Look where buttons and gauges are the same as VTI but are scaled down to fit a smaller display.
    c. Small Display Look where the buttons and gauges are reformatted to fit a smaller display better.
4. There is only a single menu system "feel" for VTI which uses a slide-out system that covers the interface to display submenus; dismount has multiple "feels" based on the target and configuration.
    a. For the large display, the menu is displayed on the sides as in VTI, but submenus replace the main menu and never cover the main interface.
    b. For the small display, the menu is displayed as a single top bar with pull-down submenus that cover the main interface.
5. VTI has a physical yoke for tele-operation of assets; dismount can use either a software-based joystick (unique to the dismount display) or it can use a physical joystick if available; the software-based joystick is disabled and the icon disappears from the interface.
6. VTI has "high end" hardware
    a. More powerful processor,
    b. Lots of memory >1 GB,
    c. More powerful graphics card and texture memory.

Dismount has tablet-based hardware of lesser capability than the VTI

    a. Celeron processor (tablet) and Caruso processor (personal digital assistant [PDA])
    b. Limited memory 512 MB
    c. Basic graphics card capability, minimal texture memory.

3. Assessment of the Scalable Displays

3.1 Participants and Procedures

Twelve male Soldiers at Fort Knox participated in an assessment of the scaled TARDEC display designs and software features. The focus of the assessment was not simply the question of *if* the Soldier completed a particular task using the particular display but *how* the Soldier was ultimately able to accomplish the task. Each Soldier completed two tasks, a route-planning task and a tele-operation task.

The route-planning task was completed three times, once for each display configuration. Figures 5 through 7 show the displays and screen layouts. Displyay configurations for route planning were

1. Display 1 (tablet) with the large buttons - 2.5 cm (wide) by 2.0 cm (high);
2. Display 2 (PDA) with small buttons - 1.5 cm (wide) by 1.0 cm (high) (0 cm spacing);
3. Display 2 (PDA) with scaled down large buttons - 1.5 cm (wide) by 1.3 cm (high) (0.2 cm spacing);

For the route-planning task, Soldiers were asked to

1. Plan a cross-country route between four points on a map;
2. Locate an asset and assign the plan to the asset;
3. Change the map view and zoom in and out on various map locations.

Figure 5. Large display (display 1) with map view for route planning.

Figure 6. Small display (display 2 with small buttons) with map view for route planning.

Figure 7. Large display (display 1) with tele-operation view.

The tele-operation task was only used in conjunction with Display 1 (see figure 7). The hardware/software formats for tele-operation were Display 1 with the physical joystick and Display 1 with software-based joystick. The Soldiers tele-operated a small unmanned ground vehicle (UGV), TALON (see figure 8). The TALON robot is a small lightweight tracked UGV developed by Foster-Miller. The Soldiers drove the TALON in a “figure eight” pattern around a set of orange cones with the physical joystick. After one figure eight was completed, the physical joystick was removed and the Soldier tele-operated the TALON in the same pattern using the software-based joystick. The tele-operation task was completed with the TALON in the Soldier’s line of sight and in non-line of sight.

Figure 8. TALON small UGV.

3.2 Data Collection and Reduction

The data collected were self-reported. The Soldiers were queried as they were using the different displays; their opinions about the displays and their thought processes about how to complete the task were recorded. Experimenters used knowledge elicitation techniques focusing on usability heuristics to understand how the Soldier navigated through each display to accomplish the tasks. Refer to appendix A for examples of the specific questions. Video was recorded throughout the assessment.

The data were coded with the use of the Skills, Rules, and Knowledge Framework (Rasmussen, 1986; Reason, 1990) as commonly applied to Ecological Interface Design (Burns & Hajdukiewicz, 2004; Christoffersen, 1996). Skills are defined as efforts that use little or no conscious control after intention is established (Rasmussen, 1990). In the context of the operation of a UGV interface, a procedure that was conducted at the skill level of abstraction might take the form of an experienced Soldier-operator rapidly selecting icons and selecting the toggle button to activate them, all without diverting his/her attention from the primary task of maintaining situational awareness with regard to the UV and its environment. The defining characteristic of this level of operation is that the actual manual skill of selecting and activating the icons is performed without cognitive effort. The Soldier makes a decision to perform an action and then executes the action without further conscious thought. Performance of procedural tasks usually reaches the skill level when operators repeatedly peform the task until it becomes automatic and no longer requires cognitive effort to execute after the decision to enact the task is made.

Rule level processing consists of the use of relatively simple sets of rules and procedures to select a course of action in a familiar setting (Rasmussen, 1990). The use of a rule does not require underlying knowledge of the system, only knowledge of the procedure. Rule use generally requires a moderate and intermittent level of cognitive resource use since some recollection and tactical control over the various elements of the procedure are maintained. For the UGV operator, rules are likely to represent regularly used procedures. For instance, experienced Soldier-operators might know that when they experience lag between the control system and robot operations, one easy solution is to turn off the control station and then turn it back on. This represents a condition-action pair but not one that is likely to be used commonly enough to reach the skill level of abstraction. Accordingly, when an operator has used a procedure often enough to use it as a standard strategy for addressing a problem or system state but not often enough for its use to have become automatic, it is likely to be represented as a rule.

Knowledge-based processing is a more advanced level of reasoning used when a novel or unexpected situation is encountered (Wirstad, 1988). Effective use of information at this level requires a fundamental understanding of the underlying principles or laws by which a system is operated (Vicente, 1999). If perceived understanding of the system is incongruent with true system behaviors, then a series of troubleshooting and problem-solving skills will be applied. Thus, an experienced Soldier-operator encountering a new problem or executing an unfamiliar function for the first time will probably try to reason his or her way through the process, based on familiarity with other functions of the system or using other known procedural functions as a model. In the absence of the kind of deep knowledge necessary to drive this knowledge-based strategy, a serial process of finding the best applicable rule through trial and error might also be applied. Knowledge-based processing requires a very high levels of cognitive resource use, regardless of the strategy chosen, because each step in the procedure needs to be effortfully planned, executed, and monitored.

The Skills, Rules and Knowledge framework (Rasmussen, 1986; Reason, 1990) was applied to the data set as described in the following categories:

1. Did the Soldier complete the task?
2. Did the Soldier ask clarifying questions about the task?

The Soldiers were able to ask the experimenters questions throughout the experiment. The questions were asked because the Soldier did not know how to complete a single step or series of steps needed to accomplish the task. If questions were asked, it was inferred that the Soldiers did not reach a skill level on that portion of the task.

3. Did the Soldiers use their primary training on the VTI system to complete this task?

We were interested in whether Soldiers were able to use knowledge transfer from the original VTI design in order to complete the entire task with the dismounted displays. If the Soldiers could use the displays easily and did not require help from the experimenters, it was assumed that the VTI-learned skills or rules transferred between displays.

4. Did the Soldier use a knowledge-based (i.e., prior experience) solution to complete the task?

If perceived understanding of the system is incongruent with true system behaviors (i.e., VTI display had a different layout than the dismounted displays), then a series of troubleshooting and problem-solving skills would be applied, such as trial and error or serial search.

5. Was the Soldier able to confirm that an action was taken? Was feedback provided to the Soldier which could confirm that s/he had made a change in the robot?

This represents the number of Soldiers who stated that they had a high level of confidence they had made changes in the asset.

4. Results

The results are presented as the mean number of individuals who responded accordingly in the categories described in the previous section.

4.1 Performance Route Planning

Task 1: Soldiers were asked to draw a cross-country route between four Xs on the map and to use a starting point, two-way points, and an end point.

Results: Number of Soldiers who

- Completed this task: 12 (100%)
- Asked clarifying questions about the task: 12 (100%)
- Used primary skills/rules training to complete this task: 0 (0%)
- Used a knowledge-based solution to this task: 12 (100%)
- Could confirm assignment of plan asset (Feedback): NOT APPLICABLE

Task 2: Soldiers were asked to locate an asset and assign their plan to the asset:

Results: Number of Soldiers who

- Completed this task: 12 (100%)
- Asked clarifying questions about the task: 7 (58%)
- Used primary skills/rules training to complete this task: 0 (0%)
- Used a knowledge-based solution to this task: 12 (100%)
- Could confirm assignment of plan asset (Feedback): 0 (0%)

Task 3: Soldiers were asked to change the map types and zoom in and out of the map.

Results: Number of Soldiers who

- Completed this task: 12 (100%)
- Asked clarifying questions about the task: 12 (100%)
- Used primary skills/rules training to complete this task: 0 (0%)
- Used a knowledge-based solution to this task: 12 (100%)
- Could confirm assignment of plan asset (Feedback): NOT APPLICABLE

4.2 Performance of Tele-operation Task

Because of technical difficulties with the TALON (battery power and network connectivity to display), several Soldiers were not able to complete the tele-operation task with both joysticks. General observations made by the experimenters and Soldier comments are presented.

4.2.1 Observations Made

4.2.1.1 Physical Joystick

- Soldiers reported that traversing the obstacle course (particular to turning) required fine control, which was not available with the physical joystick.
- Soldiers reported physical strain from holding the joystick. They preferred a built-in joystick.

4.2.1.2 Software-Based Joystick

- The software joystick afforded the use of a precision grip.
- The software joystick was useful for fine movements.
- The software joystick allowed the Soldiers to set a constant speed.
- Soldiers reported the software-based joystick was useful for navigation through turns.
- Soldiers reported that the visual representation of speed as concentric circles was useful for proper controlling movement of the robot. This feature was not available on the physical joystick.
- With the software joystick, it took time for the Soldier to learn how to adjust the UV speed, especially during the initial learning that led to variable UV control.

4.3 General Ergonomic Findings

The experimenters observed the Soldiers using the displays and asked ergonomics-related questions and obtained subjective feedback about how difficult a location was to press on each display, the usability of buttons and menus, and preference for the different hand grips. Experimenters asked the Soldiers' opinions about using the displays in various operational settings (i.e., mounted or dismounted operations), given the size and weights of the displays.

4.3.1 General Ergonomic Findings for Display Size

4.3.1.1 Large Display (tablet)

Size - 8.25 by 6.25 inches

A. Observations

- Could not be used in a dismounted situation.
- Was easiest to use when tilted backward at least 15 to 20 degrees.
- Afforded the use of thumb presses for button activation.
  - Thumbs could not be accurately used in center of screen.
  - The use of thumbs on lower parts of the screen caused the Soldier to take his grip off the display.
- Stylus could not be used if screen was not tilted (i.e., unnatural writing position).

4.3.1.2 Small Display (PDA)

Size – 5 x 3.75 inches

A. Observations

- Afforded the use of a chuck grasp with the left hand because of the grips on the display.
- Neither thumb could be used for small buttons if Soldier had average to large fingers.
- Without researcher instruction, the Soldiers always used the right index finger.
- Left thumb could not be used to hit lower left buttons because of reach and contortion required.

B. Overall Observations (regardless of display size)

- Right hand was used more often than left hand.
- Right hand often obscured the display when crossing over to use left side buttons.

4.3.2 General Ergonomic Findings for Button Size

4.3.2.1 Large Display (tablet)

With large buttons – 2.5 cm by 2.0 cm; buttons on left and right sides of the display

A. Observations

- As the Soldier moved farther away from the sides of the display, the thumbs were more difficult to use.

- Soldiers always switched from thumb to index finger to place route points on the inside of the screen.
- Thumbs could not be used to touch buttons on the bottom of the display when the display had to be held. This is because of an unnatural movement of the thumb.
- Right-handed people were even less accurate with the left thumb than those who were left-handed.
- Soldiers had a difficult time hitting the smaller buttons on the small display. This is because it required precision to hit buttons surrounded by other buttons.

4.3.2.2 Small Display (PDA)

A. With small buttons (1.5 cm by 1.0 cm); buttons on top of the display

- 100% of Soldiers leaned into the display to read the buttons.
- Soldiers used the stylus with the smaller buttons.
- Smaller buttons were easier to press at the corners of the screen but were harder to press as the buttons cascaded.

B. With scaled down large buttons (1.5 cm by 1.3 cm); buttons on left and right sides of the display

- Soldiers preferred the size of these buttons to the larger buttons used on the large display and the small buttons used on the small display.
- Soldiers had a very difficult time using thumbs over left side buttons when the left hand was in the hand grip strap on the display.

C. Overall Observations

- The large buttons (2.5 cm x 2.0 cm) afforded the use of fingers.
- When the display had a hand grip, the buttons afford the use of thumbs.
- Soldiers preferred the smaller form factor because of the improved visual contrast and minimized amount of information on the display.

5. Discussion and Recommendations

The purpose of this usability assessment was to evaluate, through Soldier feedback and experimenter observation, the functionality of specific display features for control of UVs. The displays designs were modified from the VTI crew station. The intent was to design the smaller displays so that a Soldier could easily transition from using a larger version of a display to a smaller version and vice versa. In our assessment, we investigated whether Soldiers could make this transition as well as assess features of the displays. In this section, we discuss the findings of this assessment and the implications for future designs.

5.1 Summary of Task Performance

Overall, the Soldiers were successful in using the various display configurations to plan a route for a UV. This suggests that the displays preserved the basic functionality originally designed in the VTI crew station for completing route-planning tasks. The implementation of the functionality, however, was not sufficient for the Soldiers to be able to complete the tasks without assistance from the experimenters. All the Soldiers had to ask clarifying questions about Tasks 1 (plan a path between four points) and 3 (change the map view). Further, more than half of the Soldiers asked for clarification of Task 2 (assign the plan to an asset). These results suggest that the original display design lacked design principles that were transferable to smaller display. For example, Task 1 required users to navigate through the display and create a new route. Even though the labels and sequence of events remained the same, the locations of the buttons for this task were different than the original VTI design. The Soldiers indicated that they were also unsure where to go to assign a plan to an asset. It was not easily distinguishable as to why some accomplished this task with less difficulty than others. When we questioned the Soldiers who completed this task without asking a question, the primary answer was "*I just read all of the buttons and this one made the most sense*." Uncertainty about the functionality of buttons and the associated violation of user expectancies for the button locations may have caused the error rate on the various components of the route-planning task.

Through observation and questioning, we gained some insight into how the Soldiers completed the tasks. When a Soldier seemed to be stuck in the process of completing a task, we asked, *"what are you looking for?"; "are you looking for any key words?"; "is this similar to how you completed this task on the original display? "Please explain."; "what are you doing right now?"* Through the use of this type of questioning, the following conclusions were drawn. Most of the Soldiers used a *serial search* tactic to accomplish tasks. The Soldiers read every button until they reached the button that matched their target. Further, most Soldiers started in the upper left-hand corner of the display. Second to *serial search*, Soldiers used the *process of elimination*. When Soldiers were still unsure how to proceed, they read every button on the screen in a serial fashion (left to right and top to bottom) and chose the button that made the most sense. The final tactic used was to *ask the experimenter* how to proceed. In this case, the researcher directed the Soldiers' attention to the appropriate button. Typically, after the redirection, Soldiers were then asked, *"Would you expect to find this functionality under this button?"; "What do you think about that button functionality?"; "How did you do this in your original training?"*

Our usability assessment showed that some knowledge obtained from training on the original VTI crew station did positively affect the Soldiers' ability to use the scalable displays. Generally, Soldiers knew what the displays were used for (controlling a robot and planning) and how to hold and interact with the buttons on the display. The buttons seemed familiar to them but out of place. What did not transfer were the locations and groupings of the buttons and how to navigate through menus.

In general, Soldiers had been trained on a system that did not fully afford transfer to a smaller display. The original VTI design was a multi-display system consisting of three screens. Buttons on the screens are the roughly the same size, shape, and color. Soldiers were trained how to use the VTI crew station, that is, the location and function of each button, mission planning, and asset management. Soldiers continued to train on the system until they were confident that they could perform the necessary training objectives. Through Soldier observation and discussion, we made the determination that what made the VTI crew station easy to use was time and effort spent learning the new system. Time and effort are the two essential components for effective training (Schneider, 1985). However, the goal of scalability is not to develop training programs for each display but to develop principles and guidelines that can be used to create scalable software that requires little to no re-training. We want learning on one display to transfer to another with little cognitive effort by the Soldier.

5.2 Design Recommendations

The question then remains, how can Soldiers learn to use the new displays? The research of Rasmussen (1993) and colleagues into skills, rules, and knowledge types provides a good theoretical framework to guide scalable display design. Experience gained through training is a key indicator on whether a skill, rule, or knowledge-based solution should be used (Hammond, 1980; Rasmussen, 1993). A skill is fast, efficient, and well practiced. Skills can be practiced with the observer providing minimal cognitive effort. When the task is well practiced and easy to complete, it becomes a skill that does not require the user to engage in cognitive effort to complete the task.

A rule requires the user to attend to the stimuli and attach meaning to those stimuli. It can provide guidance toward a section of the scalable design that meets the user's needs to accomplish the objectives. One way to establish a set of scalable rules is through the use of features such as color, shape, and location of buttons. Color can be used as a redundant cue that signifies meaning to the user (Wyszecki, 1986). Shape can be used as another organizational cue that signifies meaning. The user could perceive different shapes as having different functions (e.g., "I can press these buttons but not buttons of that shape"). For example, a rule such as the "color blue always means menu" could be attached to numerous menu buttons that have different text signifying different categories. Although skills have no need for interpretation, rules can be interpreted differently according to context. Smaller blue buttons that signify menus should be selected with a stylus while larger blue buttons can be used with a finger.

Button locations can also be used to the designer's advantage. Buttons that are going to be used often should be placed at the beginning of menus or toward the top of a menu. A primary button that is used often should have space surrounding it that differentiates it from other buttons. The designer can determine the button qualities by watching users interact with the software (Lidwell, Holden, & Butler, 2003, Nielson, 1993; Nielson & Mack, 1994).

Where the user expects to find a button predicts where s/he will look first on a display. Users expect to find creation buttons such as "new" at the beginning of menus and edit buttons farther along in the menu structure. Buttons at the top of menus are expected to be used more often than buttons at the bottom of menus. Users will often scan buttons at the top of menus before looking at the bottom of a menu.

Objects grouped together are often perceived to have the similar or related functionality (Wickens & Carswell, 1995; Tversky, 1977). When buttons with varying functionality are grouped together, the group as a whole represents an organized structure to the human, which should have some common meaning though even though it does not. Further, a group with dissimilar buttons and a main button that does not describe the group as a whole will cause the user to question the logic of the system (figure 9). A user often gives feedback such as "I really don't think these buttons belong here." For example, in the display used in this assessment, the main menu button of edit did not match the sequence of buttons (new plan, add points, zoom, and select plan) that followed. The edit button lost its meaning and required the Soldier to memorize the lower menu buttons rather than group them together by functionality.

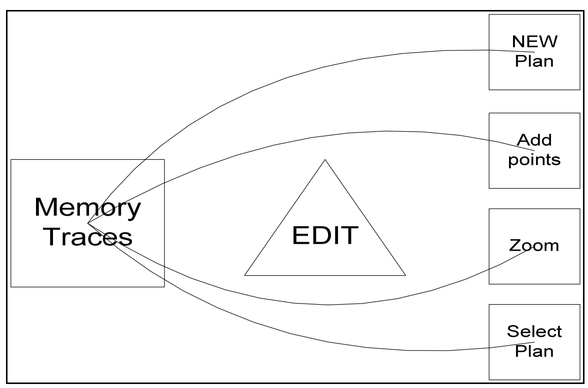

Figure 9. Inefficient menu hierarchy system.

Ineffective button grouping increases demands on working memory. Soldiers have to remember the specific locations of single buttons and not the location of a group of buttons that have similar functionality. Memory traces are more likely to be made through a main button when the functions of those buttons have similar meaning captured by the main menu button (figure 10). It is more likely that select points, add points, copy, and paste will be associated with the main button of edit than the button of new plan.

The next level of information processing important for display design is knowledge. At the knowledge-based level, information reaches the Soldier's mind and does not match an existing skill- or rule-based behavior; a Soldier will not push a button with the purposeful intent of accomplishing the task (skill) or apply a code-based behavior response and look for a sign that makes sense (rule). In this case, the Soldier does not have any rules that apply or any skills that are relevant to the new task, but the Soldiers look for cues and integrate them into their mental model of how things should or likely will work. In order to meet the goals of improving transfer of training and scalable design, it is important to elicit existing mental models and focus on design aspects that employ rather than contradict it. For example, a Soldier in the assessment stated that groups of buttons did not make sense: *"We either plan or we execute in the Army; that's how we are trained."* The reference was to the route-planning task. The experimenter wanted the Soldier to assigned a plan to an asset and have the asset execute that plan. The Soldier could not find the assigned button and stated that this order of execution should be clearly marked. In the Soldier's mental model, planning and executing are tasks that should be clearly marked and separated in the display. Thus, the Soldier's interaction with the system was hindered because the display did not match his mental model about how action and planning in the Army are presented.

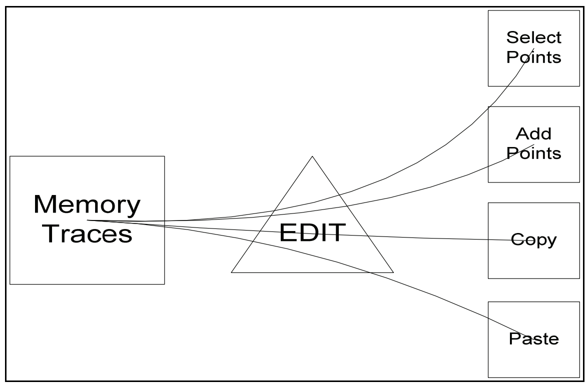

Figure 10. Efficient menu hierarchy system.

In designing a display around mental models, the designers need a common reference of how a Soldier completes a task in the component sub-tasks. The best way to understand a mental model and provide a functional display design that represents this model is through user feedback and laboratory testing. Errors are likely to be made at the knowledge-based level because the Soldier is problem solving where to go (as seen during the assessment) rather than simply making a decision about what choice will definitely be made next. According to the Skill, Rule, Knowledge model, a person might operate at the knowledge-, rule-, or skill-based level and switch between them, depending on task familiarity. As skills, rules, and knowledge relate to this assessment, we should consider the following for future design efforts:

1. During this assessment, the Soldiers did not use skill-based behavior. The Soldiers should show highly practiced movements in a nearly effortless behavior in navigating through the new display.
2. The Soldiers did not use a system of rules learned in the original display. Design principles such as color of buttons or menus, or grouping by space or location of buttons and menus that have similar meaning were not used and as such, could not meet the requirements for rule-based actions.

3. Knowledge-based problem solving occurs when a human encounters a new situation, develops a strategy, and systematically accomplishes his goal through problem solving. When asked, almost every Soldier stated that s/he identified a key word s/he was looking for and then read everything on the screen in order to accomplish the task at hand. Even though the new system was easy to read and had symmetrical buttons that were similar to the original system, we identified certain strategies the Soldiers used. These strategies are portrayed in the Soldier feedback.

Soldier comments when asked to perform the original task:

> *Experimenter – "What are you thinking right now?"*
> *Soldier - "I don't know where any buttons are"*
>
> *Experimenter – "How did you accomplish that task?"*
> *Soldier - "I'm reading all of the buttons"*
>
> *Experimenter – "Where do you start reading?"*
> *Soldier - "I start at the top left, go down, go up the top right, and go down"*
>
> *Soldier - "I don't know what buttons to hit to get to other buttons"*
>
> *Soldier - "I know I'm looking for a plan button, if it wasn't in the first I'd go to the second, then the third"*

It is likely that Soldiers in the assessment learned the original display system to a skill-based level. When confronted with a task simply go to "X" position on the three display system and push a button that leads to "Y" functions or capabilities, they were successful. However, the skills that the Soldiers learned through training are not likely to transfer to smaller displays used in our assessment because the original encoding of the skills relied on spatial memory of where the button was located, not the button's color, relationship to other buttons, categories of buttons, etc. We suggest using design principles described as rules that can be scaled across displays of all sizes and dimensions. Rules should allow the Soldiers to use decision-making skills and not problem-solving skills.

5.3 Summary of Ergonomic Findings

Overall, the ergonomically related results showed that the small display with the smaller buttons was preferred by the Soldiers to the other display configurations for dismounted operations. For mounted operations or during conditions when the Soldier would not have to be mobile, the larger display was preferred by the Soldiers we interviewed. Ergonomic results for the joysticks showed that the chuck grip, such as that on the physical joystick, is not sensitive enough for a situation when precision is needed. Precision joysticks such as the software-based joystick, are better in these conditions and those when the Soldier would be dismounted.

During the assessment, the researchers observed that many of the displays afforded the use of the thumbs. We observed that Soldiers took more time to touch buttons toward the center of the screen and were less accurate in doing so. Additionally, several Soldiers were asked how far they could comfortably use their thumbs, starting from the resting position at the edges of the screen, moving toward the center. After approximately three touch buttons, or approximately 9 cm, functionally it was difficult to use the thumbs on the display. The Soldiers often used their right index fingers to complete functions outside the thumb's range, such as completing the sequence of button presses on the sliding menu.

Fitts' law can provide guidance into developing system specifications of width and depth of menus from the side/edges of the display where the Soldiers' fingers are resting. Fitts' law states that the smaller and more distant a target, the longer it will take to move to a resting position over the target (Fitts, 1954; Jagacinski, 1989). Additionally, the faster the movement has to be and the smaller the target, the more likely error will be introduced. Speed and target size dilemmas in display design are often referred to as the "speed/accuracy trade-off". On the small displays, the buttons should be larger and have more space between them if they are to be used. On the smaller displays, designers should minimize the amount of text information presented in order to decrease the reading requirement (a difficult task in dismounted and moving conditions). Further, if the display has a left-handed grip and affords the use of the thumb, then buttons should not be placed on the bottom, left-hand side of the display. Future research should investigate hand position, menu width, and target size (button size). Based on the current data and observations, the researchers recommend no more than three buttons across for touch screen displays.

6. Future Research

For future research, we have identified four tasks to guide us toward achieving our goal of designing scalable interface concepts that facilitate the Soldiers' use of their robotic assets in dismounted and mounted mission environments:

Task 1: Identify critical tasks associated with scalable displays. Who are our Soldiers (users) and what are they trying to do? Prioritize these tasks. Examine existing display designs in use by military organizations. Specifically, employ display designs undergoing development within the military community. Identify chosen technology and catalog the different methods of user input for the display. Identify the environmental conditions in which the display can be operated in order to help determine appropriate functionality (i.e., dismounted, mounted).

Task 2: Determine hierarchy of system functionality within a task, based on mental models of Soldiers. Take a task that will be included in the scalable display and research any available task analyses, looking for key identifiers of function which should be included in the menu hierarchy.

Determine the between-task prioritization in the software and test this hierarchy through use of design principles across multiple displays.

Task 3: Identify what makes a design principle fit the category of skill, rule, or knowledge based. Use the scientific literature to gather identifiers of what is a skill, rule, and knowledge trait and match the outcome to design principles. Determine how a design rule can become skill or knowledge based. The goal is to develop design rules that can be efficiently scaled across displays, minimizing the need for additional training.

Task 4: Create a "testable" function of what is acceptable as a scalable design principle. Take a design principle across multiple display platforms and look at increases or decreases in Soldier performance. Separate principles into categories of minimally acceptable and optimal task performance.

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Appendix A. Questionnaire Template for Route Planning Task

Route Planning Tasks

1. Draw a cross country route between these 4 x's using a start point, two way points and an end point.
    a. Insert a point into the plan

Experimenter Questions:

What are you thinking about right now?
What comes to mind when I asked you to create a new route?
What did you expect?
What would you want to be there?
(For new plan)- Is that where you expected it to be?
(If lost completely) – What were you thinking about?
What should it be like or similar to (i.e., other programs that you have used)?
How did you feel about the mission button layouts?

2. Locate an asset. Assign your plan to your asset.

Experimenter Questions:

What comes to mind when I asked you to assign a plan?
What should you be looking for that makes sense to you?
Did you know where to go to find an asset?

3. Change the map types.
    a. Zoom in and out on the map type you changed to.

Experimenter Questions:

Were there any buttons that you thought were critical?
What would those buttons be?
What do think about the button size?
What do think about the button layouts?
What did you think about the colors?
What do you think about the fonts?

Objective Metrics:

How many times did they show frustration?
How many times did they choose the wrong button?
How many times did they ask for help?

Subjective Feedback:

Which display was easiest to use (Rank order them please)?
1.
2.
3.
Why 1st?
Why 2nd?
Why 3rd?

Rank order the displays for mounted missions. Assume you have to carry the display.
1.
2.
3.

Rank order the displays for dismounted missions. Assume you have to carry the display.
1.
2.
3.

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